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Recent trends, opportunities and challenges of biodiesel in Malaysia: An overview

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A B S T R A C T

Energy supply and its security issues have been the topic of interest lately. With growing environmental awareness about the negative implications brought by excessive usage of fossil fuels, the race for finding alternative energy as their substitutions is getting heated up. For now, renewable energy from biodiesel has been touted as one of the most promising substitutions for petroleum-derived diesel. Combustion of biodiesel as fuel is more environment-friendly while retaining most of the positive engine properties of petroleum-derived diesel. Production of biodiesel is also a proven technology with established commercialization activities. The huge potential of biodiesel coupled with the abundance of palm oil which is one of the most cost-effective feedstocks for biodiesel is responsible for the pledging of Malaysia to become the leading producer of high quality biodiesel in the region. Currently, total approved installed capacity of biodiesel production in Malaysia equals to almost 92% of the world biodiesel production output in 2008. While Malaysia does indeed possessed materials, technologies and marketing superiority to vie for that position, many more challenges are still awaiting. The price restriction, provisions controversy, escalating non-tariff trade barriers and negligible public support need to be addressed appropriately. In this review, Malaysia's previous and current position in global biodiesel market, its future potential towards the prominent leading biodiesel status and major disrupting obstacles are being discussed. The feasibility of utilizing algae as the up-and-coming biodiesel feedstock in Malaysia is also under scrutiny. Lastly, several recommendations on the roles played by three major forces in Malaysia's biodiesel industry are presented to tackle the shortcomings in achieving the coveted status by Malaysia. It is hope that Malaysia's progress in biodiesel industry will not only benefit itself but rather as the role model to catalyst the development of global biofuels industry as a whole.

Contents

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1. Introduction

Since the commencement of industrial revolution in the late 18th and early 19th, energy has become an indispensable factor for human to preserve economic growth and maintain standard of living. The widespread of industrial revolution in Europe had been largely attributed by the high availability and accessibility of coal as the primary source of energy. Meanwhile, the advent of automobiles, airplanes and electricity had been made possible by the energy usage of petroleum in the twentieth century. Since then, coal and petroleum have become the main sources of energy to human beings. Until today, energy has been continuously derived from conventional sources such as coal, petroleum and natural gas. Despite the discoveries of various alternative energies particularly renewable energy from biofuels and solar, fossil fuels remain as the largest contributor to satisfy the global energy demand. In 2006, the combine total of petroleum, natural gas and coal represents more than 83% of the world total primary energy production as shown in Fig. 1 [1]. On the other hand, in Malaysia, the fossil fuels contribution to the total primary energy production stands at 95% in the same year as shown in Fig. 2 [2]. Primary energy is essentially raw energy which has not been subjected to any transformation or conversion process and includes natural fossil fuels and renewable energy. This dominant trend is expected to remain the same for the next twenty years to 2030 for Malaysia as it is still a rapidly developing country. Even though the market share of liquid fuels like petroleum will decline eventually due to high oil price in the future, natural gas and coal will continue to remain as an important source of energy supply due to the former being more efficient and less carbon intensive than other fossil fuels while the latter being one of the cheapest and most abundant source of energy available [3]. Malaysia itself is also promoting the usage of coal as a fuel of choice for power generation before nuclear power becomes viable in order to free up more natural gas for exports and reduce dependency on petroleum.

The energy generates from the combustion of fossil fuels has indeed enabled many technological advancements and social-economy growth which otherwise may be impossible. However, it simultaneously creates several environmental concerns which can threaten the sustainability of our ecosystem. One of the primary concerns will be the emissions of greenhouse gases and other types of air pollutants such as sulphur dioxide, hydrocarbons and volatile organic compounds (VOCs). In U.S., the release of greenhouse gases resulting from the combustion of petroleum, natural gas and coal amounted to more than 80% of total anthropogenic greenhouse gas emissions during the year of 2006 [4]. The breakdown of energy-related carbon dioxide emissions, which is the highest contributor to anthropogenic greenhouse gas, by region in 2006 and also projection to the year of 2030 are shown in Table 1 [5]. It is predicted that the emissions of greenhouse gases by fossil fuels will increase by 39% in 2030 if no tremendous effort are thrown in to mitigate it. As shown in Fig. 3, the total carbon dioxide emissions from fossil fuels in Malaysia has been increasing every year since 1998 except only for the year in 2005 [6]. Huge accumulation of those gases in our atmosphere will eventually lead to drastic climate changes, acid rain and smog. In addition, the activities of harvesting, processing and distributing those fossil fuels are mostly energy intensive which may bring subsequent detrimental effects to our ecology system.

Even then, development and economic growth of a country are affected considerably by how much the demand for energy is adequately met. Therefore, fossil fuels continue to be utilized

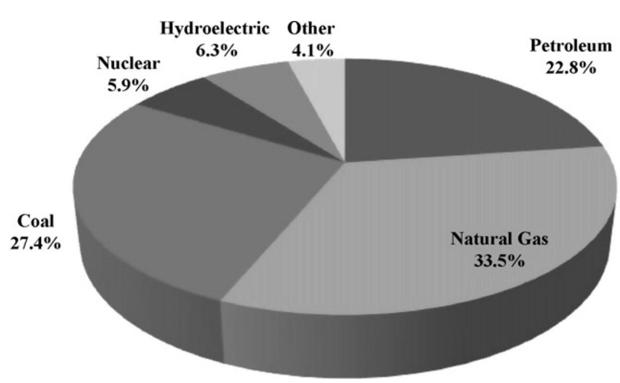

Fig. 1. World primary energy production in 2006 by source.

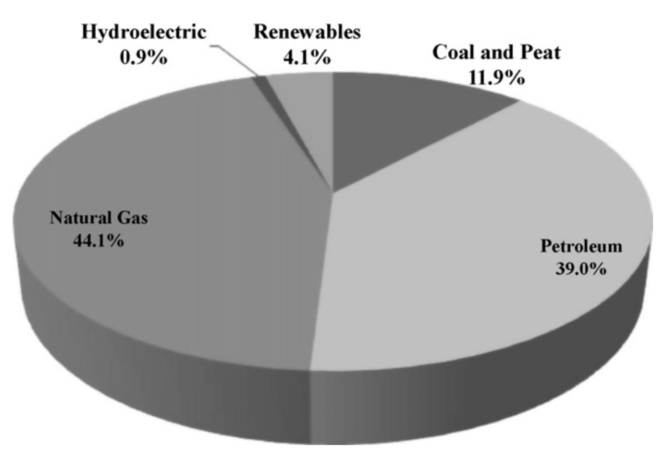

Fig. 2. Malaysia primary energy production in 2006 by source.

Table 1
World energy-related carbon dioxide emissions by region in 2006 and 2030 (billion metric tonnes).

Region	Actual (2006)		Projections (2030)	
	Amount	Percentage (%)	Amount	Percentage (%)
OECD				
North America	6.9	23.8	7.7	19.1
Europe	4.4	15.2	4.5	11.1
Asia	2.2	7.6	2.4	5.9
Non-OECD				
Europe and Eurasia	2.9	10.0	3.4	8.4
Asia	9.0	31.0	17.0	42.1
Middle East	1.5	5.2	2.3	5.7
Africa	1.0	3.4	1.4	3.5
Central and South America	1.1	3.8	1.7	4.2
Total World	29.0	100.0	40.4	100.0

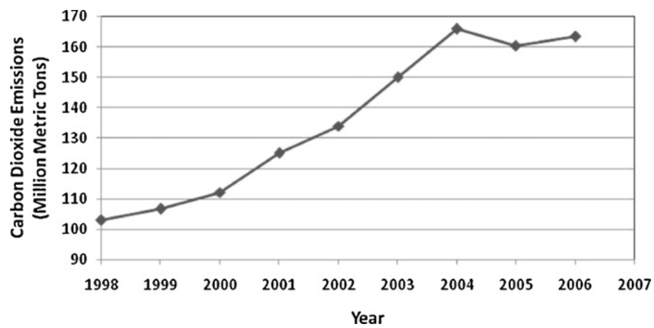

Fig. 3. Malaysia total carbon dioxide emission from consumption of fossil fuels.

extensively particularly by those developing countries despite protests from several environmental activist groups. Realizing the fossil fuels as a double-edged sword, many different types of alternative energy have been explored which have the possibility of satisfying the world energy demand while simultaneously ensuring the sustainability of the environment. One such renewable energy in particular will be biodiesel which is mainly derived from vegetable oils or animal fats and has shown great potential to serve as a substitute to petroleum-derived diesel for compression ignition (CI) engine [7]. Malaysia is one of the countries which actively advocates for the commercial production and usage of biodiesel as fossil fuels replacement due to its rich palm oil resources. The current approved installed capacity for biodiesel production is about 10.2 million tonnes in Malaysia [8].

The next section in this review will discuss briefly about the development and prospects of biodiesel in Malaysia. A thorough understanding of the past will serve as a better lesson for the future work. Significant foreign contributions are also being highlighted. Then, three major components making up of biodiesel in Malaysia; the feedstocks, production technology and products, are singled out for further discussion. The third and fourth chapters will be dealing with Malaysia's distinctive strengths and opportunities towards becoming a leading country in biodiesel production. The following chapters after that will account for the various challenges facing Malaysia biodiesel industry as well as exploring opportunity in utilizing new biodiesel feedstock, algae. Last but not least, several recommendations are presented from the author's point of view regarding the prospects of Malaysia becoming a leading figure in biodiesel production.

1.1. History and potential of biodiesel

Biodiesel, which can also be known as fatty acid methyl ester (FAME), is produced from transesterification of vegetable oils or animal fats with the addition of methanol as shown in Fig. 4. In general, the liquid has similar composition and characteristics when compare to petroleum-derived diesel such as cetane number, energy content, viscosity and phase changes. Therefore, when blended together with petroleum-derived diesel, it can be used in any CI diesel engine without any modifications. Several of its distinct advantages such as lower greenhouse gases emissions, higher lubricity and cetane ignition rating compare to petroleum-derived diesel have enabled biodiesel to become one of the most common biofuels in the world.

The usage of vegetable oils in diesel engine could be dated back to the year of 1900 when Rudolf Diesel, the inventor of the engine that beared his name, demonstrated peanut oil as fuel in Paris World Fair. Their usage continued until 1920s before petroleum-derived diesel almost completely eliminated vegetable oils in the market due to cheaper price, higher availability and government subsidies. This lead to the alteration of diesel engine by manufacturers in order to utilize lower viscosity petroleum-derived diesel and thus rendered the usage of vegetable oils no longer feasible. In 1970s, fossil fuels supply shortage and security had prompted renew interest in developing vegetable oils as alternative energy. However, the altered diesel engine is no longer suitable for high viscosity and low volatility vegetable oils to be applied directly. Refinement has to be made in order to turn those vegetable oils into quality fuel. Several methods have been investigated such as pyrolysis, blending [9,10] and microemulsification [11] to lower the viscosity of vegetable oils. Yet, they still pose problems including carbon deposition and contamination [12]. Therefore, transesterification process has became the most viable process to transform the vegetable oils to be used in CI engine.

A Brazillian scientist, Expedito Parente filed the first patent for industrial production process of biodiesel in 1977. Meanwhile,

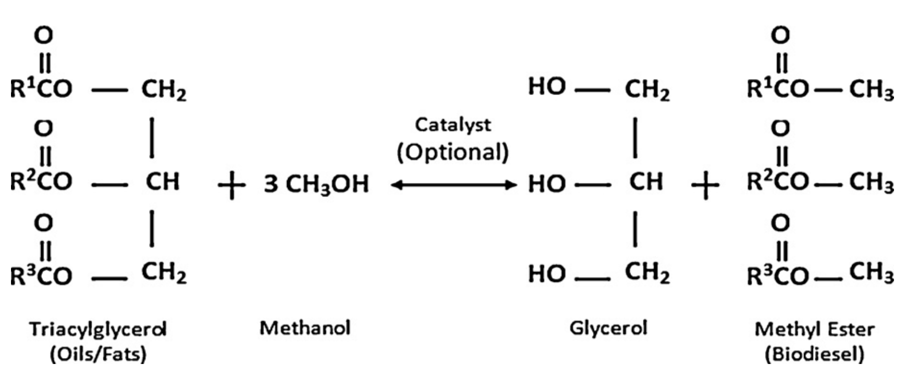

Fig. 4. General equation for transestification of triacylglycerol.

research for the production and refining of biodiesel using sunflower oil was initiated in South Africa in 1979. However, increasing subsidization in petroleum market had impeded any other significant breakthrough being achieved. Not until in the late 1990s that growing concerns about the environment sustainability and decreasing cost differential had driven the growth in commercial production of biodiesel. During that period, biodiesel plants were being constructed across many European countries such as Czech Republic and Germany. France launched the local production of biodiesel fuel known as 'diester' from rapeseed oil while U.S. National Renewable Energy Laboratory experimented with algae as the biodiesel source in the 'Aquatic Species Program'. National Biodiesel Board in U.S. had reported production of 1.9 million liters of biodiesel in 1999 while the following year in 2000 saw that figure increased more than ten folds to 25.4 million liters [13]. In 2004, the Government of Philippines had made it compulsory for the incorporation of 1% of coconut biodiesel blend in diesel fuel for use in government vehicles [14]. Elsewhere in U.S., Minnesota had became the first state in the nation to mandate the use of diesel fuel with at least 2% of biodiesel blend in 2005. Biodiesel as a proven fuel was further bolstered when ASTM International (ASTM) published new quality specifications for biodiesel blends in 2008. Now, biodiesel blend fuel is available at many normal service stations across Europe and U.S. while the world biodiesel production output is estimated to be 11 million metric tonnes in the year of 2008. By 2010, total biodiesel production can be as high as 20 million tonnes. The largest aircraft manufacturer, Boeing plans to start using biodiesel in its air carriers in 2014 which will surely increase the biodiesel demand substantially in the future.

1.2. Development of biodiesel in Malaysia

Since early 1980s, Malaysian government had realized the importance of developing biofuel and in particular, biodiesel in the long term. Being the world's largest producer and exporter of palm oil, it was imperative that Malaysia emerged as one of the pioneers in the palm biodiesel industry. This was achieved through the aggressive stance by Malaysian Palm Oil Board (MPOB) when the project of developing palm biodiesel was initiated at laboratory scale in 1982. Encouraging results from laboratory research had subsequently enabled the commencement of palm oil biodiesel pilot plant construction two years later in 1984 with collaboration from local oil company, Petronas [15]. The pilot plant had been successfully commissioned to produce 3000 metric tonnes of palm oil methyl ester annually.

During the subsequent year, palm oil biodiesel had been invariably subjected to various systematic evaluations as petroleum-derived diesel fuel replacement. Laboratory testing, stationary engine evaluation and field trials had been carried out successfully on a large number of diesel-powered vehicles including taxis, commercial trucks, passenger cars and buses [16,17]. One of the tests was mounting 36 Mercedes Benz of Germany onto passenger buses running on 3 types of fuels, namely, pure petroleum diesel, 50% blend of palm diesel and 100% pure palm diesel. The outcome of the test showed promising results as both of the fuels containing palm diesel were comparable to pure petroleum diesel in terms of the expected life of engine and total mileage covered [18]. In 1992, research on palm oil biodiesel successfully developed winter-grade biodiesel production technology which solved the gelling issue when biodiesel is used under cold condition near freezing temperatures. However, even though extensive laboratory research and field trials had been conducted from time to time [19–21], no major breakthrough had been achieved mostly due to weak industrial demand and inconsistent political support.

Stagnation in Malaysia's biodiesel industry continued until the Fifth Fuel Policy was announced under the Eighth Malaysia Plan (2001–2005). This policy was revised from the earlier Four Fuel Diversification Policy in 1981 where its aim was to prevent over-dependence on oil as the main energy resource. Under this new policy, renewable energy was declared as the fifth fuel in the energy supply mix in Malaysia [22]. Thereafter, greater efforts had being undertaken to encourage utilization of renewable resources and this had developed renewed interest in biodiesel. In order for the development of biodiesel to gain more momentum, Government of Malaysia had drafted the National Biofuel Policy in 2005 to carve out a comprehensive framework and concrete initiatives for use of biofuels in Malaysia. This policy entailed a four-prong strategy which was aimed to reduce Malaysia's petroleum-derived fuel import bill, further promoting the demand for palm oil which was expected to be the primary commodity for biofuels production in Malaysia, as well as to shore up the price of palm oil especially during the period of low export.

Henceforth, development of biodiesel in Malaysia had been growing by leaps and bounds. MPOB had partnered with one local plantation company to build the first biodiesel refinery in Labu, Negeri Sembilan during late 2005. Biodiesel status as a renewable energy source was further solidified in the country when Envo Diesel had been introduced in late 2006. Envo Diesel was a mixture of 5% blend of processed palm oil with 95% petroleum-derived diesel. It was different from conventional biodiesel B5 blend in which it used straight palm oil instead of methyl ester. This new type of biodiesel would initially be used in government vehicles before gradually extending its usage to industrial and transportation sectors in 2010. Malaysia's annual diesel imports is estimated to be at 10 million tonnes. By using Envo Diesel, it can save up to 0.5 million tonnes of diesel imports or equivalent to USD 380 million a year. According to Malaysian Biodiesel Association (MBA), there are 10 active biodiesel plants in the country with a total annual biodiesel installed capacity of 1.2 million tonnes as shown in Table 2. An additional four biodiesel plants with combined annual capacity of 190,000 tonnes are expected to commence commercial production by the end of 2009 [23]. Until now, 91 biodiesel licenses

Table 2
List of active biodiesel plants in Malaysia 2008.

No.	Name of production company	Plant location	Plant capacity (tonnes/year)
1	Carotino Sdn. Bhd.	Pasir Gudang, Johor	200,000
2	Malaysia Vegetable Oil Refinery Sdn. Bhd.	Pasir Gudang, Johor	110,000
3	PGEO Bioproducts Sdn. Bhd.	Pasir Gudang, Johor	100,000
4	Vance Bioenergy Sdn. Bhd.	Pasir Gudang, Johor	200,000
5	Mission Biotechnology Sdn. Bhd.	Kuantan, Pahang	200,000
6	Carotech Bio-Fuel Sdn. Bhd.	Ipoh, Perak	150,000
7	Lereno Sdn. Bhd.	Setiawan, Perak	60,000
8	Golden Hope Biodiesel Sdn. Bhd.	Teluk Panglima Garang, Selangor	150,000
9	Global Bio-Diesel Sdn. Bhd.	Lahad Datu, Sabah	200,000
10	SPC Bio-Diesel Sdn. Bhd.	Lahad Datu, Sabah	100,000

have been issued by Malaysia's Ministry of Plantation Industries and Commodities and new license applications have been freezed temporary in fear of overgrowing.

1.3. Foreign investments/collaborations

Foreign investments or collaborations play a vital role in ensuring the continuous and vibrant growth of Malaysian biodiesel industry. During the early development stage, MPOB had collaborated with various foreign companies and varsities such as Brandies University from U.S., Prignitzer Eisenbahn (PE) Arriva from U.K., Cycle & Carriage and Diamler-Benz from Germany. In 2005, 100 tonnnes of palm biodiesel was sent to PE Arriva in Germany for field trial on the diesel-powered trains. The encouraging results from the test had built higher confidence in other European biodiesel investors and thus laid a solid foundation for more extensive commercial cooperations in the future. Two years after that, in 2007, Australian based company, Mission Biofuels had successfully commissioned its first biodiesel plant and plan was undertaken to set up a second plant which will cement the company status as the largest biodiesel producer in Malaysia. During the same period, Enertech Co., Limited, a Korean biodiesel company, had sought the expertise and know-how technology from MPOB to commission a 60,000 tonnes per year of biodiesel in Pyeongtaek Port. This had proven that Malaysia's palm oil biodiesel processing technology was at the forefront compare to other countries. The potential of Malaysia to emerge as one of the key biodiesel players was given higher recognition when two more foreign companies, Japanese Yanmar and Middle East Dubai Group threw in their investments in Malaysia's biodiesel industry in 2008. Yanmar opened a biodiesel research facility in Malaysia to conduct research and development for biodiesel fuel while Dubai Group made a USD 49.5 million investment in Malaysian biodiesel company, Global Bio-Diesel (GBD) [24]. Similarly in the same year, Carotech Bio-Fuel Sdn. Bhd. had successfully inked a USD 57 million contract with Swiss-based Trafigura Beheer BV, the world's third largest independent oil trader to supply 60,000–84,000 tonnes of biodiesel a year to Europe. On the other hand, Malaysia had also secured a tripartite biodiesel venture involving Malaysia, Uganda and Libya to construct a 250,000 tonne-capacity plant in Port Dickson, Negeri Sembilan which is scheduled to be completed in late 2010. Undoubtly, those investments have helped to push the development of biodiesel in Malaysia to a greater height.

2. Biodiesel

One of the advantages of producing biodiesel as an alternative energy lies in its wide range of feedstock available. The feedstock for biodiesel can be different from one country to another depending on their geographical locations and agricultural practices [25]. Selecting the best feedstock is essential to ensure low biodiesel production cost. Feedstock supply and price alone cover more than 75% of the overall biodiesel production cost [26] as depicted in Fig. 5. In order for the biodiesel to remain competitive compare to petroleum-derived diesel, feedstock should be available at the lowest price possible and in aplenty. Other desirable properties for biodiesel feedstock include high oil content, favourable fatty acid composition, low agriculture inputs (water, fertilizers, soils and pesticides), controllable growth and harvesting season, consistent seeds maturity rates and potential market for agricultural by-products [25]. In general, they can be divided into 4 main categories which are listed as below.

1. Edible vegetable oil—rapeseed, soybean, sunflower, palm and coconut oil.

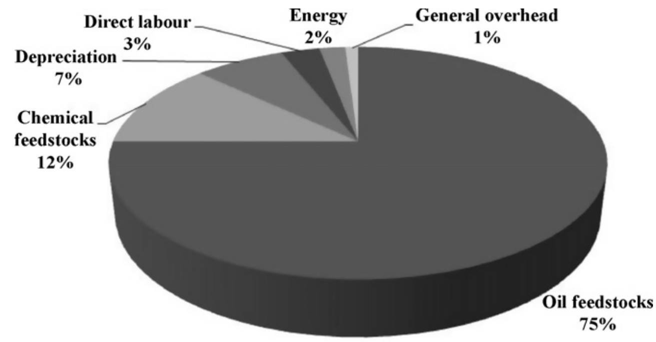

Fig. 5. General cost breakdown for production of biodiesel.

2. Non-edible vegetable oil—jatropha, karanja, sea mango, algae and halophytes.
3. Waste or recycled oil.
4. Animal fats—tallow, yellow grease, chicken fat and by-products from fish oil.

2.1. Palm oil

In Malaysia, biodiesel production is synonymous to palm oil. To date, all of the established biodiesel production chains in Malaysia are using palm oil as primary feedstock. As a matter of fact, the thriving plantation of palm oil is the main factor which drives Malaysia towards developing biodiesel production and technology. Therefore, the availability and accessibility of palm oil supply are crucial in determining the potential growth of biodiesel production in Malaysia. Different from other countries such as U.S. which mainly utilizes soybean oil while Europe utilizes rapeseed oil, biodiesel produced in Malaysia from palm oil offers several distinct advantages. Besides requiring less manual labour for harvesting, oil-palm plant is also well-known with high yield of vegetable oil. A hectare of oil palm can produce approximately five tonnes of palm oil, compared with other vegetable oils like rapeseed and soybean, which can produce one tonne and 375 kg each [27]. This is almost 5 times and 10 times higher yield than rapeseed and soybean respectively with the same area of land. Palm oil production cost per unit is also the lowest among other oil crops, followed by soybean with 20% higher costs than palm oil while rapeseed is the highest [28]. This has enabled the price for palm oil biodiesel generally to be lower than rapeseed or soybean oil counterparts in the commodity market as shown in Table 3. The palm trees that produce oil have absorbed a lot more CO_2 during photosynthesis to form biomass for the other parts of the plant. The tree continues to absorb CO_2 throughout its life span of 25–30 years [29]. This perennial crop also contributes in releasing a large quantity of O_2 to the atmosphere, far exceeds those emitted by other annual crops such as soybean and rapeseed. Moreover, oil-palm agriculture is essentially a man-made green forest yielding timber and fibre in

Table 3
Price comparison of biodiesel from different feedstock.

Feedstock	Price of crude vegetable oil (USD/tonnes)	Price of B100 biodiesel (USD/tonnes)
Rapeseed[a]	815–829 (Ex-Dutch Mill)	940–965 (FOB NWE)
Soybean[a]	735 (FOB Rosario)	800–805 (FOB Rosario)
Palm oil[a]	610 (Del. Malaysia)	720–750 (FOB SE Asia)
Waste cooking oil[b]	360	600 (estimated)
Animal tallow[b]	245	500 (estimated)
Jatropha[c]	N/A	400–500 (estimated)

[a] Source: Kingsman.
[b] Source: Rice.
[c] Source: Goldman Sachs.

addition to oil seeds as co-products. It contributes significantly towards biodiversity since oil-palm plantation has many similarities to that of a well-grown forest.

Biodiesel produced from palm oil has also proven to be of higher quality in several attributes as fuel than those produced from soybean and rapeseed oil. The differences arise due to the fact that palm oil biodiesel contains higher level of molecular saturation, which means lower number of double bonds in the molecules. This leads to a higher ignition quality in CI engine. However, this also leads to a higher cloud point which makes them difficult to be used in cold weather unless certain cold flow additives are being added [25]. Production of biodiesel from palm oil has also sparked several controversial issues notably the fuel versus food debate [30,31] and clearance of indigenous rainforests [32]. Even then, the future of palm oil biodiesel still looks promising. The strong demand in other countries especially in Europe once more biodiesel blends have been implemented for transportation usage will drive a more vibrant exportation and production of palm oil biodiesel in Malaysia.

2.2. Jatropha curcas

Comparing to palm oil biodiesel industry, biodiesel produced from jatropha is still in its nascent state in Malaysia even though considerable interest has been shown lately by both the government and private sectors. The potential of using jatropha as feedstock for biodiesel production has received much attention worldwide [33,34] and even acknowledged by Goldman Sachs, U.S. leading investment banking and securities firm [35]. The company had estimated that jatropha based biodiesel will be among the potential feedstock to produce the cheapest biodiesel as shown in Table 3. It has been mentioned that this plant has high drought-resistance and can survive in harsh conditions such as in gravel, sand and saline areas [33]. This enables non-arable land to be utilized for jatropha plantation which can provide a high yield in return. India, for example, has already planted jatropha along the side of railroads with yield reported around 1.5–2 tonnes per hectare. This is higher than rapeseed or soybean oil albeit less than palm oil. Moreover, jatropha is an inedible crop and thus will avoid falling into the controversy of fuel versus food [30–31]. From economical viewpoint, jatropha crops do not require much fertilizer and water. Thus, its plantation cost can be significantly reduced to render the price of biodiesel produced from jatropha extremely competitive with diesel from fossil fuels without government subsidies. Recent study has also proven that a 40–50% jatropha biodiesel blend with petroleum-derived diesel could provide optimum performance without any engine modifications or preheating [36].

However, even with much attention being diverted to jatropha, the fact remains that it is still a relatively unknown crop with few thorough scientific research data available. This has created confusions regarding its optimal planting conditions and thus led to unpredictable output and lower yield than expected. Its seeds also do not ripen evenly and required huge manpower for seed collections due to unpredictable characteristics of its perennial life cycle [35]. As jatropha oil is found to contain as much as 34 wt.% of saturated fatty acids, jatropha based biodiesel is expected to exhibit poor operability at low temperature [37]. Furthermore, lack of price benchmark or market mechanism for jatropha has laid uncertainty to the revenue stream and prevented industrial companies to invest it in a larger scale. Therefore, jatropha in Malaysia is widely regarded as a supplementary feedstock for biodiesel production instead of an alternative especially during high crude palm oil prices when producing biodiesel from palm oil will incur profit losses. In this context, jatropha based biodiesel can come in to fill the gap to ensure steady supply of biodiesel production and exportation. Realizing this fact, Malaysian Rubber Board which has been put in charge of jatropha research in Malaysia, encourages its farmers to grow jatropha only on marginal land not suitable for other crops such as palm oil or rubber. Marginal land is defined as an area where cost-effective production is not possible under given side conditions (soil productivity), cultivation techniques, agriculture policies, macro-economic and legal conditions [38]. Local private companies such as Asiatic Centre for Genome Technology Sdn. Bhd. (ACGT) have also been experimenting on jatropha and its various aspects including genomics. In 2007, National Tobacco Board was entrusted to gauge the feasibility of cultivating this crop on bris soil in the northern part of the country. Before 2008, jatropha plantation was mainly developed in East Malaysia with scattered small-scale plantations less than 40 thousand hectares. In 2008, Mission Biotechnology had contracted 80 thousand hectares of farmland in Malaysia to grow jatropha. The total land area is expected to increase up to 0.6 million hectares and 1 million hectares by the end of 2009 and 2010 respectively. It is likely that development of jatropha in Malaysia will grow only at a moderate rate in the near future as Malaysian government does not hope to over-emphasize on jatropha which may disrupt its own palm oil plantation equilibrium while at the same time does not wish to lose out on any benefits it may offer to the local biodiesel industry.

2.3. Waste oil/animal fats

Comparatively to vegetable oils, using waste oil or animal fats as biodiesel feedstock in Malaysia has not been introduced for commercialization yet although research by various Malaysian varsities have been on-going several years ago [39,40]. Recently in 2009, a Malaysian company Intrack Technology Sdn. Bhd. based in Rawang claimed that they possessed the technology to process 60 tonnes of waste vegetable oil into biodiesel and planned to further improve the process through more research before pushing it into the market. Conversion of waste oil into biodiesel is believed be able to reduce water pollution as the waste oil is usually discarded into the rivers. Since waste or recycled oil is generally inexpensive, using it to produce biodiesel can drive down the production cost significantly compare to the other feedstock as shown in Table 3. However, the production process will be very challenging as it will need to handle a wider range of process parameters and impurities to produce high quality biodiesel which meets international standards such as ASTM D 6751 and EN 14214 [41,42]. This feedstock can also induce more corrosion problems to the pipelines and requires a more robust cleaning strategy. In addition, the available supply of waste oil is estimated to be very much less than the petroleum-derived diesel used for transportation and heating purposes. The same case can be extended to using animal fat below the premium grade for human consumption as biodiesel feedstock. Its usage to produce biodiesel can add more value to its waste management system while replacing a small percentage of petroleum-derived diesel in the market which it will otherwise be simply discarded. The main obstacle of using this type of feedstock is mainly due to the difficulty encountered in waste collection system as its sources are normally scattered. As biodiesel from these sources are acknowledged to be the cheapest compare to other oils, Malaysian government should not be neglecting its local potential in helping Malaysia replacing its local petroleum-derived diesel demand.

2.4. Multi-feedstock production

Multi-feedstock production will be very advantageous as it can reduce dependency on single feedstock and thus avoid price volatility in order to produce large volume of high quality biodiesel

economically. This is crucial especially in the view of the increasing probability of using biodiesel to replace billions liters of diesel fuel market globally. Furthermore, diversifying biodiesel feedstock portfolio will increase the process flexibility and attractiveness to investors. For instance, the cost of a more expensive feedstock can be used to blend with a cheaper feedstock in order to maintain the same profits. However, the main obstacle is to ensure the quality of the biodiesel still meets the specifications set by ASTM D 975 for biodiesel blends and ASTM D 6751 for B100 pure biodiesel. Multi-feedstock biodiesel production will enhance the probability of higher product contamination, instability and variability compare to single feedstock. Even then, the solution is widely believed to be solvable with the advancement of production technology and processing experience in the time to come once multi-feedstock production has gained maturity. For example, additive system to improve the stability of multi-feedstock biodiesel production has started to be applied in biodiesel industry after more intensive research. Recent encouraging results from blending of various feedstocks on biodiesel fuel properties have also been reported by Park et al. [43], Sarin et al. [12] and Moser [44].

The long-term objective will be to eventually change the biodiesel marketing strategy to focus primarily on fuel attributes such as cloud point, oxidative stability, cetane number and not the feedstock itself. The efficiency of multi-feedstock biodiesel production in incorporating distinctive charateristics of different feedstock to produce a higher quality biodiesel fuel will determine the level and pace of development in the future. In Malaysia, the widely available and overly publicized palm oil for biodiesel production has largely prevented the development of multi-feedstock biodiesel production. So far, only one Malaysian company, Grand Inizio Sdn. Bhd. had claimed to develop the multi-feedstock biodiesel technology in January 2009. The Malaysian government are content to focus all efforts towards promoting palm oil biodiesel for now. However, to become one of the leading biodiesel producer countries in the world, development of multi-feedstock biodiesel production will be a necessity in the future. Over-dependency on palm oil alone will repeat the history of fossil fuels as evident from the impact of rising price for crude palm oil in the commodity market and environmental concerns regarding clearing of rainforests. Despite the shift of focus away from palm oil is still unlikely to take place in the near future, Malaysia has positioned itself in a comfortable starting grid. The agronomics and processing technological advancement coupled with effective marketing strategy in palm oil biodiesel from Malaysia have gained recognition from all over the world. Therefore, it is foreseen that changing to multi-feedstock biodiesel production in Malaysia should not possess much hindrances.

2.5. Production technology

The technology for biodiesel production in Malaysia is mostly originated from Malaysian Palm Oil Board. Its vast experience and active involvement in research and development since 1980s has successfully translated the knowledge into commercial application with the aid of LIPOCHEM, an industrial company specialized in palm oil refineries. Three demonstration plants were built in early 2000s by using MPOB's technology and in 2005, the scaling up for annual production of 60,000 tonnes was completed. Since then, many companies both local and foreign have sought the production technology from MPOB.

Currently, the present production technology utilized by MPOB is based on basic catalyst transesterification. A cheap basic catalyst, NaOH which is easily available is used in the production process. Even though the basic catalyst is cheap and economical, the only setback is that the feed will need to have low amount of free fatty acids and moisture content. The feed will be initially subjected to a series of refining processes and the refined feed is called Refined Bleached and Deodorised Palm Oil/Olein (RBDPO). This is the refined product from crude palm oil after undergoes degumming, caustic refining by caustic soda, bleaching to remove pigments and the final stage being high temperature vacuum deodorization [25,45]. The refined feed will mix with excess methanol and catalyst before heated to the reaction temperature. After the required temperature has been attained, the reactants will be passed through multi-stage continuous reactors in series to maximize the reaction conversion and ensure reaction completeness. After each stage of the reactors, glycerol which is produced as the by-product will be removed from the subsequent stream in order to push forward the reaction for higher reaction conversion rate. After the reaction has been completed, both the excess methanol in biodiesel and glycerol stream are recovered by flashing through flash vessels and distilled by using methanol purification column with structured packing before recycled back to feed stream. The crude glycerol free from methanol will then be stored in storage tanks. Meanwhile, the crude biodiesel is sent for cleaning, polishing and cooling before stored in storage tanks. The crude biodiesel will be washed several times by using hot water and then separated by centrifugal separation. In order to ensure low moisture content for the final product, the stream will also be subjected to drying process under vacuum. A schematic diagram for the process flow is shown in Fig. 6 [46].

MPOB claims that this technology can achieve a minimum overall biodiesel yield of 98% after optimization and the biodiesel products meet the full specifications as underlined by EN 14214 and ASTM D 6751 as shown in Table 4 [46,47]. The by-product, glycerol will also attain a high purity around 85%. This technology

Table 4
Comparison of fuel characteristics of Malaysian diesel, normal CPO methyl ester and winter-grade CPO methyl ester with ASTM D 6751 and EN 14214 standards.

Characteristics	Diesel	Normal CPO methyl ester	Winter-grade CPO methyl ester	ASTM D 6751	EN 14214
Ester content (% mass)	–	98.5	98.0–99.5	–	96.5 (min)
Free glycerol (% mass)	–	<0.02	<0.02	0.02 (max)	0.02 (max)
Total glycerol (% mass)	–	<0.25	<0.25	0.24 (max)	0.25 (max)
Density at 15 °C (kg/L)	0.853	0.878	0.87–0.89	–	0.86–0.89
Viscosity at 40 °C (cSt)	4.0	4.4	4.0–5.0	1.9–6.0	3.5–5.0
Flash point (°C)	98	182	150–200	130 (min)	120 (min)
Cloud point (°C)	–	15.2	−18 to 0	–	–
Pour point (°C)	15	15	−21 to 0	–	–
Cold filter plugging point (°C)	–	15	−18 to 3	–	–
Sulphur content (% mass)	0.1	<0.001	<0.001	0.0015	0.001 (max)
Carbon residue (% mass)	0.14	0.02	0.02–0.03	0.05 (max)	0.3 (max)
Cetane index	53	58.3	53.0–59.0	47 (min)	51 (min)
Acid value (mg KOH/g)	–	0.08	<0.3	0.8 (max)	0.5 (max)
Copper strip corrosion (3 h at 50 °C)	–	1a	1a	3 (max)	1
Gross heat of combustion (kJ/kg)	45,800	40,135	39,160	–	–

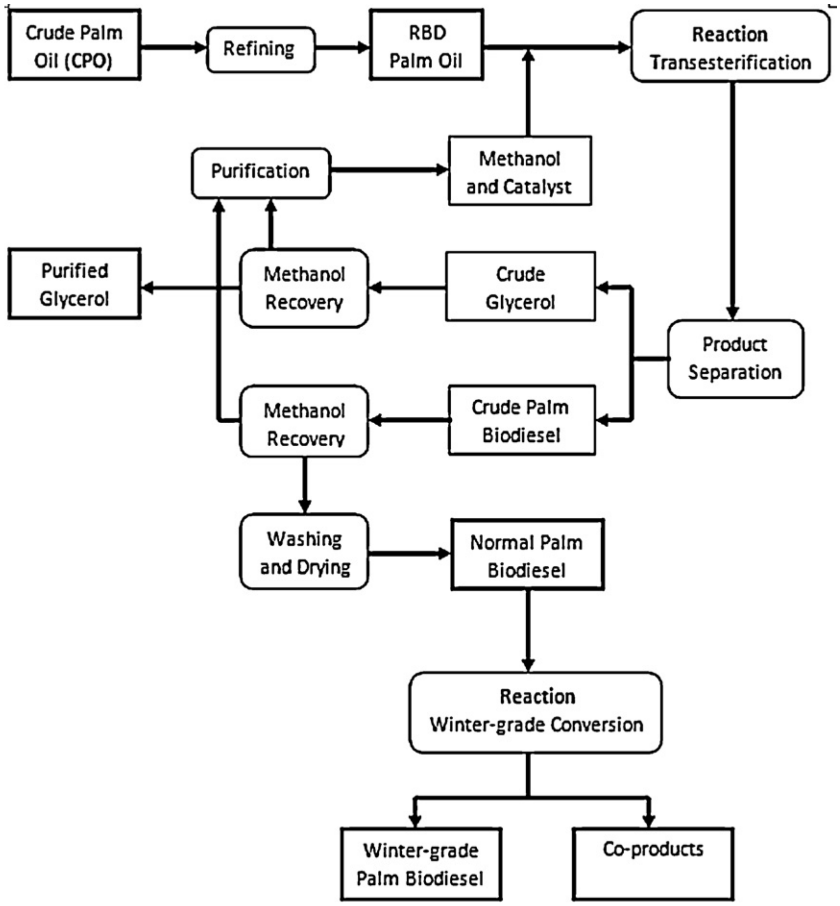

Fig. 6. Schematic diagram for palm biodiesel processing by MPOB.

is also very economical as only low pressure and temperature are required and the commissioning time is considerably short. Under normal conditions, full specification standards can be achieved in less than 24 h after feeding of RBDPO. Many improvements for the process to reduce both operational time and cost are under consideration. One of the improvements involves skipping several refining treatment and adding crude palm oil directly as feed through esterification as the intermediate process. Another suggestion is to implement vertical integration of palm oil biodiesel in which the biodiesel production process is optimized starting from the oil-palm plantation [48]. The excess energy can be utilized more efficiently thus reducing processing cost and increasing sustainability criteria. As basic catalytic transesterification process has been long established, a complete overhaul of process scheme to other type of processes such as using enzymes [49] or supercritical condition in the absence of catalyst [50] seems very unlikely. However, other feasible changes such as using acidic catalysts for higher free fatty acids and moisture content in the feed will need to be considered as multi-feedstock biodiesel production becomes the trend in the future.

2.6. Primary products

As opposed to other biodiesel production countries, Malaysia has been showcasing its own brands of biodiesel based on palm oil as the results of decades-long research by MPOB. Since 2001, various blends of crude palm oil and palm oil products such as RBDPO and medium fuel oil (MFO) with petroleum-derived diesel have been evaluated as boiler fuel and diesel substitute [51–54]. In March 2006, Malaysian government had officially launched a new type of biodiesel named as Envo Diesel [55]. Envo Diesel is different from conventional biodiesel B5 blend in the international market in which it uses 5% of refined palm oil (RBD Palm Olein) instead of palm oil methyl ester to mix with 95% petroleum-derived diesel. MPOB hopes that this new type of fuel can revolutionize the biodiesel industry especially in transportation as the cost of refined palm oil per liter is about USD 0.58 cheaper than palm oil methyl ester with the same volume [56]. Thus, this will render Envo Diesel more competitive in terms of commercial profits compare with using palm oil methyl ester. However, the implementation had encountered several obstacles particularly from diesel engine manufacturers. Japan Automobile Manufacturers Association (JAMA) had refused to extend their engine warranty on the usage of Envo Diesel as they still had some reservations on the effects of this new type of fuel in their engine. Some of the concerns regarding direct usage of vegetable oils in CI engine include filter plugging, fuel system corrosion and material incompatibility. Moreover, this type of fuel is more susceptible to solidify at higher temperature and thus not suitable for usage in certain temperate countries. In response to the problems, MPOB had commissioned an independent testing body and seek expertise from Shell to carry out exhaustive 'no-harm' evaluation tests and obtain technical data to convince the engine manufacturers. So far no negative results have been reported from the trials yet.

Apart from that, MPOB has also successfully developed and patented a new type of winter-grade biodiesel from palm oil methyl ester under Malaysian Patent PI 20021157 [57]. It has a lower pour point than 15 °C for conventional palm oil biodiesel while complying fully with international standards as shown in Table 4. This winter-grade biodiesel is specially designed for

exports to targeted temperate countries (from as low as −20 °C during winter) where complaints are received about conventional palm oil biodiesel clogging the diesel engine due to solidification at colder temperature [58]. The lower pour point characteristic is achieved by removing high melting components from conventional palm oil biodiesel. The separation process involves partial crystallization of the esters follows by separation of the solids from the liquid fraction similar to the one described by Kerschbaum et al. [30]. The yield of this process is varied between 35 and 40% depending on the pour point requirements. Even though the yield is low, the co-products from this process can be utilized as summer grade fuels or as raw materials for oleo-chemical industry. The introduction of winter-grade biodiesel is able to open up more market opportunities for exportation especially to European countries while enable palm oil derived biodiesel to enhance its status as a primary feedstock for biodiesel compare to soybean and rapeseed biodiesel.

2.7. Secondary products

Similar to other fuel production processes, processing of biodiesel has also produced other co-products as well. As a matter of fact, the quality of co-products from biodiesel production process is equally important to that of biodiesel in determining the continuous growth of biodiesel industry. As the price for petroleum-derived diesel is still low, expensive feedstock for biodiesel will not be able stay competitive economically by just depending on biodiesel as the single selling product. In this context, the selling of co-products can help to mitigate the effect of rising feedstock cost while maximizing the profits from biodiesel production. For some feedstock, the co-products sometimes contain higher value than biodiesel itself albeit can only process in a small quantity at a time. Examples of these palm oil derivatives being profitably developed in Malaysia are high grade Vitamin E (tocotrienols and tocopherols), carotenoids and biodegradable surfactants. MPOB has successfully developed processors to recover these valuable products and estimated that the revenues generated from the sales is sufficient to cover for most of the investments. One tonne of palm oil methyl ester has the potential to extract 0.6 kg of carotenoids, 0.8 kg of Vitamin E, 0.5 kg of phytosterols and 0.4 kg squalene with value up to USD 970 [47]. Demands for these derivatives in healthcare industry are also on the rise as they have several unique characteristics in fighting diseases such as stroke and cancer [59]. This implies that Malaysia can become a major phytonutrients producer which is estimated to possess a multi-billion dollar market potential. Meanwhile, one of the main co-products from transesterification process, glycerol is found to have the potential to be used as alternative energy replacing propane [60] apart from its conventional usage as chemical feedstock for polyurethanes. Even some of the oil-palm biomass such as trunks, empty fruit bunches, shells and fibre could be used to generate electricity. Therefore, it is imperative for the development of biodiesel co-products production chain to grow in tandem with the biodiesel industry itself so that both sides could reap extra benefits from the symbiotic development.

3. Unique features

Malaysia possesses a few strengths of its own in order to become a leading producer and exporter of biodiesel country in the world. Until now, Malaysia has already fully geared towards achieving that goal backed by almost 30 years of scientific research by MPOB. Even then, there are still several obstacles which need to be overcome as many other countries have also committed themselves to achieve the same objective in biodiesel industry. Malaysia will need to utilize its own advantages in biodiesel industry resourcefully to establish its biodiesel pioneer status globally.

3.1. Abundance of raw material

As mentioned earlier, Malaysia's richness in palm oil is the primary driving force for its development of biodiesel industry. Palm oil is previously second-most widely produced edible oil after soybean oil until in the 2004–2005 marketing year, when 33.53 million metric tonnes of palm oil was being produced globally surpassing soybean oil which recorded only 32.60 million metric tonnes [61]. Since then, palm oil production continues to increase with a higher rate compare to soybean oil. In the 2007–2008 marketing year, palm oil world production stands at 41.31 million metric tonnes while soybean oil production registers at 37.54 million metric tonnes. Out of the total palm oil production, 42.5% is produced by Malaysia alone, seconded only to its neighbouring country, Indonesia. In terms of the total exportation of palm oil, Malaysia remained as the biggest palm oil exporter with 14.21 million metric tonnes which accounted for almost half of the total exportation of palm oil in the world. Therefore, Malaysia does not need to rely on foreign import for raw materials to develop its own biodiesel industry unlike other countries. Furthermore, using raw materials from Malaysia's own plantations will enable biodiesel developers to control the cost and quality of the biodiesel production more efficiently [48].

3.2. State-of-the-art processing technology

Since 1980s, the research and development of palm oil biodiesel had been carried out by MPOB with full support from Malaysian government. Initially, the main objective of this research is to diversify the usage of palm oil in order to enlarge its exportation market. However, in the late 1990s, the advent of Kyoto Protocol and increasing awareness of environmentalism had cemented the status of biodiesel as one of the renewable energy for fossil fuel substitutions. Thus, the focus has since then been shifted to promote the usage of palm oil in biodiesel production without neglecting its role for food industry. With 30 years of research experience, the maturity of biodiesel processing technology in Malaysia is being recognized worldwide. With the aid of this technology, Dubai Ventures, a subsidiary company from Dubai Group has planned to set up a 500 thousand metric tonnes per annum biodiesel production plant in Lahad Datu, Sarawak [24,62]. When the production commences, the plant will become one of the largest biodiesel production plant in South East Asia. Apart from scaling up, this technology also promises low production cost by incorporating energy saving features and optimization process. Furthermore, the novel winter-grade palm oil biodiesel is also successfully being produced through this proprietary technology which is able to withstand colder temperature in temperate countries. So far, Malaysia has exported its palm oil biodiesel production technology to numerous countries including South Korea, Japan, Netherlands and Indonesia. By ensuring Malaysia constantly staying in the forefront of biodiesel production technology through intensive research and development, it will certainly help to establish Malaysia's leader status in biodiesel global industry.

3.3. Comprehensive marketing strategy

Malaysia has also developed a comprehensive marketing strategy in order to promote its palm oil biodiesel to the rest of the world. Amidst the efforts from Malaysia to import larger quantities of palm oil to U.S. and European countries, the major markets for crude palm oil (CPO), various negative campaigns and

claims have been targeted towards palm oil. The propaganda masterminded mainly by association from importers' country such as American Soybean Association (ASA) was intended to undermine the credibility of palm oil in order to protect their own markets and profits [63]. They degenerated palm oil and coconut oil as tropical oils which could lead to heart disease when use for human consumption. In response to these smearing campaigns, Malaysian government with the aid of other non-governmental organization were quick to launch their own counter offensive campaigns to educate the public from misleading information. Several visits by Malaysian government officials were arranged in order to clear the doubts rose from those propaganda. Eventually, MPOB had successfully gathered enough scientific evidence to back their claims that palm oil is actually safe for human consumption and this had prompt for the premature ending of the defamation campaigns.

Every now and then, palm oil based products including biodiesel are still subjected to various prejudices and prejudgements from international bodies. However, having garnered experience from previous encounter, Malaysia is able formulated concrete plans to rectify the problems. Other organization such as Roundtable on Sustainable Palm Oil (RSPO) and Palm Oil Truth Foundation are being formed in order to circulate real facts regarding palm oil development and its products in particular, palm oil biodiesel. Over the years, Malaysia has managed to increase its palm oil exports to 15.41 million metric tonnes covering more than 100 countries all around the world [64]. These firmly established export marketing networks and trust will surely play a pivotal role in cementing Malaysia status as the leading producer of biodiesel in the world.

4. Advantages to nation

Being the leading producer of biodiesel in the world will bring many benefits to Malaysia. Apart from exportations, job opportunities and environment, securing this prestigious status will also signify Malaysia's readiness and preparations towards achieving the status of developed country on par with other countries such as Japan, U.S. and Canada. This can also serve as a good example to demonstrate Malaysia's capabilities in the international stage and thus raise the country's own self-esteem. In the long run, this will surely create higher motivation or spur more interest for Malaysia to pursue other relevant objectives or goals and thus transforms the country to become more competitive globally.

4.1. Exportations

One of the immediate benefits from larger production of biodiesel will be the revenues generated from the exportation to other countries. According from MPOB, total revenue generated from exportation of biodiesel had amounted to USD 172 million in 2008. As environmentalism begins to widespread and many countries are eager to comply with the international regulations to reduce their green house gases emissions, demand of biodiesel has skyrocketed in recent years. Many countries are now revising their biodiesel policies in a reactive or proactive manner. In 2003, the European Commission had proposed a plan to eventually replace 5.75% of petroleum fuel in the transportation sector with biofuels by 2010 [63]. This is expected to create an additional demand of 10.2 million tonnes of biodiesel per year by 2010. Five years after that, they adopted a revised requirement in which all transportation fuels in EU were mandatory to contain a minimum 10% renewable content by 2020. European countries own domestic production is unlikely to catch up with the above objective and thus has to rely on imports from other countries. A large portion of this demand is expected to be met by imported palm oil and this represents a huge opportunity for Malaysia. Meanwhile, in the U.S., the biodiesel blend of B5 and B20 is already widely used. Many U.S. states such as Minnesota and Washington have passed legislations to mandate the use of biodiesel in their fuel with many more legislations favouring biodiesel usage will be implemented in the near future [46].

Compare to ethanol, the tariff rate for biodiesel is generally lower, at around 5% in most OECD countries [65]. This permits a potential higher market penetration of palm oil biodiesel to those countries. As more and more net oil importer countries such as Japan, South Korea and Australia begin to substitute their fossil fuels with more environment-friendly fuels, larger biodiesel demand will be created and all of them can become the potential export market for Malaysia's palm oil biodiesel. Moreover, it is estimated that Malaysia will become a net oil importer country by 2015 [66] and the biodiesel production can meet the local market demand for petroleum-derived diesel thus help to reduce foreign exchange losses from fossil fuels imports.

4.2. Job opportunity

Besides, strong growth in biodiesel industry will also create ample job opportunity for Malaysian workers. For example, investments by Mission Biotechnologies in its biodiesel refinery in Kuantan, Pahang is believed to be able to improve the economy of the town by bringing in hundreds of job opportunities and promote other value-added activities. The benefit is not only limited to the biodiesel production industry, but can be extended to other related upstream and downstream industries as well. A strong and stable growth of biodiesel industry will also encourage more active agriculture activities in particular for oil-palm plantations in Malaysia. The added demand for palm oil as the results of diversifying its usage will certainly increase its market value and attracts more investments. Furthermore, the increasingly important usage of palm oil has also created many economical opportunities for other downstream processing activities. Oleo-chemicals industry which uses palm oil as well to produce soaps and cosmetic products can also thrive from the increasing supply and regulated market. Thus, improving growth of biodiesel industry can actually trigger the advancement of other industries which are closely related to each other. In overall, this can help to reduce the country's total unemployment rate and strengthening its economic ability.

4.3. Environment

Another advantage of increasing production of biodiesel in Malaysia will be in terms of environmental benefit. Malaysia has envisioned itself to achieve the status of developed country by the year of 2020. As a developed country, Malaysia will be categorized as Annex 1 country under the definition in United Nations Framework Convention on Climate Change (UNFCCC). Under Annex 1 countries category, Malaysia will need to oblige to the Kyoto Protocol treaty to reduce their emissions of green house gases to target below their 1990 levels. Since most of the green house gases in Malaysia are emitted from transportation sector due to usage of fossil fuels, biodiesel can act as the replacement fuel which boasted reduction of green house gases emission by as high as 80% depending on the feedstock employed [26,67,68]. Exhaust emission testing also shows a reduction in hydrocarbons, carbon monoxide and particulate matter emissions compare to fossil fuels. Higher production scale of palm oil biodiesel will enable higher penetration of biodiesel used to replace petroleum-derived diesel in local transportation sector. Therefore, Malaysia will be able to sustain its green economy and development without sacrificing much of its productivity. This is also evident from the

fact that not only transportation sector will adhere to the green policy but agriculture sector as well.

Previously, lack of sustainable regulations in local agriculture practices had caused clearance of large areas of rainforest with high conservation value. Usage of fire for the preparation of land for oil-palm plantations had also raised concern about the problems of forest fire and haze. These had posed a serious threat to the biodiversity in the ecosystem and render biodiesel produced from those sources not sustainable at all. As a result, the Roundtable on Sustainable Palm Oil has been formed in order to address the sustainable issues pertaining to the usage of palm oil products. RSPO has set comprehensive criteria and principles for sustainable palm oil production targeted to major stakeholders from all parts of the commodity chain in both consuming and producing parties. Consequently, agriculture sector now are required to follow a set of stringent procedures and traceability protocols in order to obtain RSPO certification [69]. Other industries related to production of biodiesel are very likely to follow suit in order to transform the whole production chain into environment-friendly system. The success of Malaysia to turn green will surely become a role model for other developing countries to emulate and this will in turn drive a larger initiative towards protecting the environment from emissions of green house gases.

5. Challenges in biodiesel industry

Even though Malaysia is now one of the leading biodiesel producers in the world, lots of effort from both government and private sector still need to be focussed on it. As a lot of other countries have also shown similar interest to develop their own biodiesel industry, it is a matter of time before the advantages enjoyed by Malaysia today will no longer become its only privileges [68]. Therefore, in order to maintain its advantages and sustain its biodiesel pioneer status, several obstacles which posed significant challenges to the Malaysia's biodiesel industry will need to be addressed and dealt accordingly.

5.1. Relative pricing

Prior to 2002, most of the vegetable oil prices in commodity market were independent from that of fossil fuels. Statistical correlation between them was actually negative where the price for vegetable oils would fall when the price for fossil fuels increased and vice versa. However, ever since vegetable oils have been used to produce biofuels in much larger scale, their prices have become closely linked as shown in Fig. 7 [70]. Consequently, the subject of biodiesel feedstock pricing relative to fossil fuels has emerged as the single most important and crucial factor in determining the profitability of biodiesel industry. As high as 75–90% of the total biodiesel production cost is actually used for purchasing the required raw materials alone. Thus, higher cost of raw materials compare to fossil fuels will represent lower profit gains and lower competitiveness to replace petroleum-derived diesel in the market. The same condition applies to Malaysia where the relative price of palm oil greatly affects its biodiesel production activities. In early 2008, the world commodity market had entered the period of expensive crude oil as its price had increased substantially until it was traded at USD 147.27 per barrel on July 2008, a historical high price for crude oil [70]. During that time, Malaysia heavily promoted its palm oil biodiesel industry as a viable alternative to expensive fossil fuels. The hype around palm oil biodiesel also increased significantly due to increased in stockpile [71] and attracted worldwide attention as the price of crude palm oil and crude petroleum oil continue to fall during the same period as shown in Fig. 5 [72]. However, all the anticipation surrounding biodiesel began to wane when price of crude oil dropped drastically to around USD 40 per barrel due to economic crisis and weakening demand. Production of biodiesel from palm oil was no longer economically feasible as its retail price would need to stay close to that of cheaper petroleum-derived diesel. To make matter worse, the stark decrement of crude oil had also triggered the same crash in crude palm oil price which threatening its supply security and jeopardized the long-term contracts required to develop the biodiesel industry. As a result, most of the licensed biodiesel plant in Malaysia had to either reduce or cease their production operations. This has hampered the efforts of Malaysian government to mandate the use of B5 biodiesel blend in privately owned diesel-powered vehicles.

As evident from above, the feasibility of turning palm oil into biodiesel is very much determined by the relative pricing of crude palm oil compare with crude oil instead of the price of crude palm oil alone. An estimated cost breakdown for production of palm oil biodiesel is presented in Table 5 [46]. Low crude palm oil price during the times of low crude petroleum oil is still not a viable option in the free market. Moreover, fossil fuels are continuously being heavily subsidized by the Malaysian government. Without compulsory demand or similar subsidy for biodiesel, it will be hard to compete with petroleum-derived diesel in the near future [68]. Malaysian government will need to deal with fluctuations in palm oil price relative to fossil fuels and uncertainty in palm oil biodiesel demand in order to develop its biodiesel industry to a newer height.

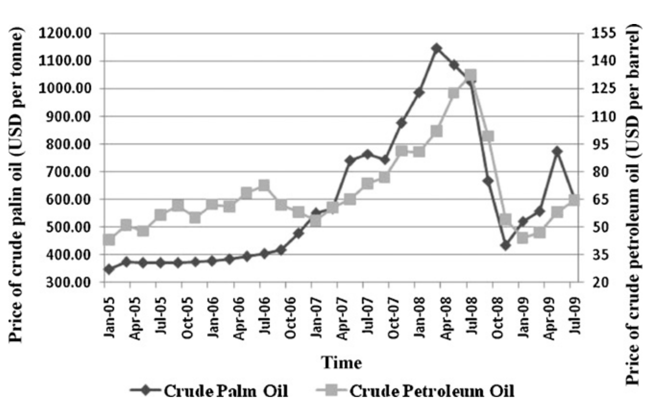

Fig. 7. Price comparion for crude palm oil and crude petroleum oil.

Table 5
Estimation of economy analysis for palm methyl ester biodiesel production in Malaysia.

Item	Cost (USD/tonne)
Crude palm oil (A)	725
Variable cost of production (excluding palm oil)	
Refining cost adjusted for PFAD and yield loss in refining	26
Chemicals (methanol, etc.)	56
Catalyst (2% sodium methoxide)	18
Utilities	10
Yield loss (2%)	15
Labour, consumables and other direct overheads	8
Total variable cost (TVC)	133
Fixed cost	
Financing cost (1 million MT/yr plant)	18
Total overheads	35
Depreciation (6.7% for over 15 years)	13
Working capital cost (2 months)	9
Total fixed costs (TFC)	75
Glycerine credit (B)	(20)
Breakeven cost for palm methyl ester (C = A + TVC + TFC − B)	913

5.2. Food and environment debate

Even though biodiesel is touted as the green fuel, biodiesel derived from edible oil has attracted numerous criticism and doubts from environmentalists. With millions of people suffer from malnutrition every year, large conversion of food crops such as rapeseed and soybean to biodiesel instead of food seems to be morally wrong [30,31]. Palm oil which production capacity has surpassed soybean oil as the world's leading edible oil is under no exception. As a matter of fact, palm oil is widely used as cooking oil and can be found in a variety of processed food as part of the ingredients such as margarine, biscuits and even chocolates. High demand for palm oil in food industry is mainly due to its healthier properties in the amount of saturated and unsaturated fatty acids compare to the other vegetable oils. It is virtually free from trans fats and contains high amount of medium-chain triglycerides (MCT) as well as antioxidants [72]. Various non-governmental organizations (NGOs) put the blame to the rapid expansion of palm oil biodiesel on the issue of escalating prices for oil and fats in the world commodity market [73]. They claim that the increment of palm oil for biodiesel has created a shortage in palm oil supply, driven up its price and threaten to destabilize governments in low-income countries.

Besides the food debate, rapid expansion of oil-palm plantations to support the extra demand from biodiesel has also being linked with several environmental issues. Large area of peatlands is being destroyed while deforestation has continued at a much higher pace to free up more land for oil-palm plantation. As oil-palm plantations encroached further into forested areas, biodiversity of the ecosystem will be severely threatened. Extinction of orang utan was one of the major problems being highlighted by environmentalists. The usage of fire to clear large amount of rainforests and peatlands could in fact release more CO_2 to the atmosphere than burning fossil fuels alone [74]. These would seriously cast doubts on the sustainability of palm oil biodiesel as opposed to those formerly perceived. Moreover, efforts by government and industrial party through RSPO to bring the environmental issues pertaining to oil-palm plantations under control are also being heavily criticised. Lack of effective stern action from RSPO is being cited which lead to failure to curb the deforestation activities. More proactive actions from Malaysia are needed to tackle the environmental issues to prevent them from affecting its exportation potential as several importer countries such as European Union has already started to impose sustainability conditions on all imported palm oil biodiesel into their country.

5.3. Exportation barrier

Under the World Trade Organization ruling, all its member countries will need to adhere by certain regulations to promote free market and liberalize international trades. However, each country still has total freedom in imposing certain limits or non-tariff trade barriers to their imports if they are deemed to pose any detrimental effects to their country. That is the case faced by Malaysian palm oil exports when EU started to implement its Renewable Energy Directive (RED) in 2008 on the pretext of sustainability and environment. Under this new directive, all biofuel sources are required to have a minimum life-cycle carbon emission saving of 35% compare to fossil fuels and not coming from lands of high biodiversity or carbon stocks [75]. Indirect land-use change (ILUC) due to the crops plantation will also need to be taken into account. By 2018, the figure can increase up to 60% which is believed will disqualify many Malaysian biodiesel export companies. Without certifications from accreditation organization such as International Sustainability and Carbon Certification (ISCC), Malaysian companies in exportation of palm oil biodiesel to EU will be severely affected. Unlike ISCC, the certification from RSPO which is largely being pursued by Malaysian palm oil exportation companies is regarded as insufficient to fully meet the sustainable and environmental requirements under RED. Moreover, there is increasing support for the EU to raise the carbon emission saving threshold to 45% in the bid to further reduce the emissions of green house gases while simultaneously include social standards such as obligation for producers to conform to International Labour Organization accords on equal pay and child labour. This will certainly pose a significant challenge to biodiesel industry in Malaysia which is primarily export-oriented to show evidence that their products fulfil the required carbon savings targets, environmental and social standards underlined by RED.

Apart the direct effects from EU's RED, the biodiesel trade issues confronting exports of subsidized U.S. biodiesel to the EU which is heavily criticized as being distorting biodiesel price and trade may also affect Malaysia's biodiesel exports. The confrontation erupted when European biodiesel producers filed an official legal complaint to the European Commission against U.S. subsidized biodiesel in 2008. According from European Biodiesel Board (EBB), U.S. measure which allowed for a minimum biodiesel blends to be subsidized before being exported has deprived European biodiesel producers of their rightful share in the growing market. Under U.S. ruling, producers of B99 biodiesel blend will automatically qualify for subsidies amounting to approximately USD 285 per tonnes. Investigations carried out have found that some of the blends are simply made from mixing of cheap pure biodiesel from Malaysia or Indonesia with as little as 0.1% or even less percentage of petroleum-derived diesel. This 99.9% biodiesel blend can then be marketed in Europe as pure biodiesel where it is again eligible for European blending subsidy schemes. As a result, U.S. biodiesel exporters can undercut EU biodiesel prices by as much as 30% and severely affecting competitiveness of European biodiesel producers. This lead to the implementation of a five-year import tariffs on U.S. biodiesel in order to help EU biodiesel producers counter the above practice [76]. Even though Malaysian biodiesel exports was only indirectly involved in this dispute, being one of the cheaper feedstocks available, the indication of growing political protection mechanism in European biodiesel industry will be a worrying trend. It will be imperative for Malaysian government and exporters to ensure that the EU sustainability and protective scheme does not discriminate against them in order to secure a stable development for the future.

5.4. Government policy

It has been proven that strong government support and policy enforcement will play a pivotal role in determining the success of biodiesel industry. In terms of financial profitability and supply infrastructure, biodiesel industry is still very much behind conventional oil and gas industry. Naturally, most of the private sector will be unwilling to commit itself to such a big risk unless most of the political and geographical barriers have been removed. Without the cooperation from private sector, Malaysian government will be hard to push its biodiesel industry to a greater height. Thus, drafting and implementation of policy pertaining to biodiesel industry will have to focus on providing the necessary support in terms of both soft and hard infrastructure while encouraging their investment through various incentive schemes. During the earlier stage, Malaysian government was lauded for its decisive implementation of policy to support the research of palm oil biodiesel through MPOB. As a result, Malaysia has managed to produce its own palm oil biodiesel production technology including winter-grade biodiesel. Extensive field trials in local and abroad to evaluate the potential of palm oil biodiesel as petroleum-derived

diesel substitute would not have been successful without full coordination from Malaysian government [77]. Inclusion of biodiesel under the Promotion of Investment Act 1986 has also enabled a total of 91 biodiesel licenses being issued as biodiesel projects are eligible to enjoy either Pioneer Status or Investment Tax Allowance (ITA). A biodiesel company under Pioneer Status can be granted tax exemption on at least 70% on its income for 5 consecutive years. Under ITA, total allowances up to 60% in respect of qualifying capital expenditure incurred within 5 years of the first capital expenditure can be awarded to the company.

The growth of Malaysian biodiesel industry begins to diminish when the price of crude oil decreased substantially. Even though Malaysia National Biofuel Policy and Malaysian Biofuel Industry Act were launched in 2006 and 2008 respectively, inefficiency of policy enforcement and sluggish response from government to address the changing market scenario has resulted in stagnation in the biodiesel industry. Out of the 91 licenses being issued, less than 20% were still active and most of the plants are actually operated far below their designated capacity. This has resulted in freezing of biodiesel licence issuance indefinitely. The long overdue implementation of mandatory biodiesel blend in private diesel-powered transportation has created disillusionment among Malaysian biodiesel producers. Without the backing of local demand for biodiesel, most of the producers have to either cut or stop their production altogether as it is unprofitable due to the current subsidized fossil fuels. In comparison, several neighbouring countries such as Indonesia and Thailand have already made it compulsory for the blending of certain minimum percentage of biodiesel in the fuel. In order to become one of the top biodiesel producers in the world, Malaysia will certainly need to have a coherent policy and proactive enforcement to restore the faith by other biodiesel developers.

5.5. Research and development

Production of biodiesel is a technology intensive industry. Apart from higher production quantity and quality, ground-breaking technology advancement is also important for shaping of Malaysia to become a leading biodiesel producer. Palm Oil Research Institute of Malaysia (PORIM) which later been changed to MPOB had been spearheading the palm oil research in Malaysia since early 1980s. Since then, lots of palm oil biodiesel technological breakthrough have been achieved notably winter-grade palm oil biodiesel and higher production efficiency by using vertical integration. Recently, Sime Darby, a Malaysian oil-palm company has announced the successful decoding of oil-palm tree DNA which is the first of its kind in the world [78]. The successful sequencing, assembling and annotating of oil-palm genome can lead to 100% increase of crude palm oil production from currently 5–6 tonnes per hectare to 10–12 tonnes per hectare annually. Assuming 4% annual replantation rate, all of the company's oil-palm plantation can be replaced with the new breed within 30 years. The oil-palm genome consists of around 1.8 billion base pairs which are the building blocks of DNA and they are closed to four times the size of the rice genome. Successful mapping of oil-palm genome can help to identify the genetic traits responsible for oil production and susceptible to disease such as basal stem rot which is one of the most harmful oil-palm diseases in Malaysia. As a result, the quality and yield of oil-palm plantation can increase drastically. Furthermore, the genetic information can also be applied to improve the harvesting period of oil palm so that the fruit will only be harvested during optimal time. Such a technological leap is important to ensure continuous progress in Malaysia's biodiesel industry particularly as Malaysia has limited arable land and being constantly attacked by environmentalists for clearing large area of rainforests. Increasing palm oil yield is one of the alternatives to increase production capacity at a lower cost.

The successful decoding of oil-palm genome is believed to pave the way for oil-palm genetic modification in the future. According to Genetic Technique Law in Germany, genetic modification organism are organism whose genetic material were being modified in a way which is not found in nature under natural conditions of crossbreed or natural recombination. The use of genetic modification in oil bearing crops such as oil palm offers potential to produce higher quantity and quality of oil. Oils with fatty acid composition which has higher resistance to excessive oxidation can also be produced from the modifications while maintaining certain desirable flavour compounds. Many research have also been carried out in order to develop palm oil with a higher level of unsaturated fats. With the increasing maturity of biochemistry and molecular biology techniques such as DNA recombination and site-directed mutagenesis, more ground-breaking results are expected to be produced [79]. Even then, extensive evaluation, regulatory testing, control and approval will be required prior to large-scale commercialization activities. The controversial side of genetic modification technology will remain an issue for Malaysian government to be carefully handled in the future so that it will be part of the solutions rather than problems in the long run.

5.6. Raw material

Malaysia's over-dependency on palm oil as the main feedstock for biodiesel production will also be one of the challenges which need to be addressed. As with the case of fossil fuels, over-dependency on palm oil for larger scale biodiesel production will certainly drive up the price of crude palm oil and thus render the production not economically feasible. Moreover, over-dependency on a single feedstock will lower its supply security and make it difficult for large-scale biodiesel production [68]. This is evident for the current scenario where the relative higher price of crude palm oil compare to crude oil has a direct detrimental effect towards the production of biodiesel in Malaysia. The uncertainties and problems clouded the future of oil-palm plantation have certainly undermined the possibility of Malaysia to become one of the leading biodiesel producer with palm oil as the sole raw material. Realizing this fact, Malaysian government has already started the initiative to explore opportunities from other raw materials especially jatropha. While Malaysian government should continue to build its biodiesel industry around palm oil, it should develop other promising feedstock simultaneously. The ability and timing of Malaysia's biodiesel industry to shift from the current palm oil biodiesel production to multi-feedstock biodiesel production will play a huge role in ensuring its security and sustainability development for the future.

5.7. Public support

Another challenge to Malaysia's biodiesel industry will be in terms of garnering sufficient public support and increasing public awareness on the biodiesel industry. As of right now, general public awareness in Malaysia's biodiesel industry still remains low. Most of the advocates for biodiesel development in Malaysia involve only the government, related industry players and certain environmentalists. Majority of the public is either ignorant or has limited knowledge on the biodiesel issues in Malaysia. While this might be due to the fact that diesel-powered vehicles account for only 5% from the whole motor vehicle population in Malaysia, the public need to be made aware that these issues will eventually become more relevant to them in the future [68]. Moreover, more alternative usages for biodiesel apart from transportation have been discovered such as heating oil, aviation fuel and electricity source [25]. As Malaysian government has rolled out plans to

implement the 5% mandatory blending of biodiesel with petroleum-derived diesel for private-owned vehicles, the public will need to be informed or educated through proper channels so as not to create confusions among them. This can also curtail the spread of certain misleading information related to usage of biodiesel while maintaining the transparency of Malaysia government policy. Apart from that, increasing public awareness can also provide additional support for the biodiesel industry in Malaysia. The public must be prepared to sacrifice their money for a cleaner environment and be willing to pay extra for the biodiesel. This in turn will drive the motivation for the biodiesel development in Malaysia either through the efforts of private or public sector. The recent public declaration to support the cause of biodiesel in U.S. is one of the fine examples involving higher participation from the public [80]. The strength and breadth of support showed by the public is vital to attract more investments and efforts to develop biodiesel industry. Therefore, it will be a huge task for Malaysia to encourage greater public involvement and garner their support in developing its biodiesel industry.

6. Feasibility of algae as biodiesel feedstock

Usage of algae as biodiesel feedstock has attracted worldwide attention recently. Algae have been cited as one of the best feedstock for biodiesel compare to other crops such as soybean, rapeseed and even oil palm. This is due to the several distinct advantages production of biodiesel using algae can enjoy as listed below.

1. Higher oil productivity (at least 15 times higher oil yield per hectare than conventional crops such as palm, rapeseed and jatropha).
2. Fast reproduction (biomass doubling within 3.5 h during exponential growth).
3. Non-food source.
4. Not necessary require arable land and fresh water.
5. Sequestration of CO_2 and wastewater treatment (absorbs CO_2 along with nitrates and phosphates while releases oxygen and water).
6. Rich in valuable co-products (Spirulina-EX and biomass for animal feed).

Algae are actually not a new research topic in Malaysia. The earliest development of phycology in Malaysia were contributed by the scientific expeditions to the east comprising mainly of the "Preussische Expedition nach Ost-Asien from 1859 to 1863, the British H.M.S. Challenger Expedition in 1874, the Dutch Siboga Expedition from 1899 to 1900 and the "Deutsche Limnologische sunda Expedition" in 1929 [81]. Those expeditions resulted in collections of mainly marine algae in Malaysia being enumerated and published [82,83]. The Tropical Fish Culture Research Institute which was a joint venture between Malaysia and the United Kingdom was founded in Malacca during 1957 to conduct research on the taxonomy, distribution and ecology of Malaysia's freshwater algae. Further research activities had been conducted with support from United Nations on unicellular algae as aquaculture food source in 1982. Since then, many publications on research activities of algae have been published [84,85]. In the past, most of the research on algae had been focussing on identification of indigenous Malaysian microalgae, usage in wastewater treatment, bioindicators of heavy metal pollution and control of mosquito breeding [81]. As algae emerged as one of the promising feedstock for biodiesel production, research on this renewable energy field has started to emerge in Malaysia among academic researchers [86] and also private companies. A large pilot scale plant utilizing CO_2 from flue gases as the CO_2 source for algae in ponds and photobioreactor had been built in Kuala Lumpur and is expected to be completed in 2009.

The feasibility of mass cultivation of algae in Malaysia can be judged from its extensive coastline surrounded by numerous islands which can provide various ideal habitats for proliferation of algae. Apart from that, Malaysia with plenty of under-utilized rice land is also an ideal spot for culturing algae. Those marginal lands are unproductive because of salt water infiltration and farmers are looking for other alternatives. Cultivation of algae can be one of them as marine algae typically grow well in the salt water. Regular collections and documentations of algae strains in Malaysia can be dated back to the year of 1859 and the total tally of Malaysian marine algae now stands at 375 specific and intraspecific taxa [84]. This huge database of algae has the potential of offering a great opportunity in exploring a more promising biodiesel feedstock for Malaysia. Moreover, as most of the electrical energy generated by Malaysia's power stations is from fossil fuels such as coal and natural gas, a lot of CO_2 will be produced and this provides an excellent supply of CO_2 for mass cultivation of algae. This can also help to sequester carbon dioxide emission to the atmosphere and thus enable Malaysia to abide the regulations set in Kyoto Protocol to reduce green house gases emissions. As Malaysia's annual diesel imports are roughly 10 million tonnes, the local demand for biodiesel after B5 mandate has been implemented will be equivalent to 0.5 million tonnes annually. In 2009, total supply of biodiesel from palm oil is expected to be 0.66 million tonnes with 0.6 million tonnes poised for exportation and only 0.06 million tonnes available for local consumption. As shown in Table 6, a hectare of oil palm generally yields 5 tonnes of palm oil and with palm oil biodiesel yield of 94%, an additional 93 thousand hectares of arable land will be needed for oil-palm cultivation to support the B5 mandate for local market. With increasing pressure from environmentalists to reduce deforestation, it will be hard for Malaysia to clear up the required land for oil-palm plantation. Meanwhile, algae which can provide 15 times higher yield than palm oil with a conservative estimation of 80% biodiesel yield requires only 7 thousand hectares of land. More than 90% amount of land can be saved for other purposes by using algae biodiesel rather than palm oil biodiesel. Even then, the land allocated for algae cultivation can be marginal land unsuitable for agriculture and thus will not compete with other existing crops.

Table 6
Land requirement comparison on biodiesel feedstocks for Malaysia's B5 mandate.

Feedstocks	Oil yield (kg/ha/year)	Conversion (%)	Biodiesel yield (kg/ha/year)	Amount of land required (thousand ha)	Percentage of arable land in Malaysia (%)
Soybean	375	95	356	1235	68.3
Rapeseed	1000	95	950	463	25.6
Jatropha	2000	98	1960	224	12.4
Palm oil	5000	94	4700	93	5.1
Algae[a]	75,000	80	60,000	7	0.4

[a] 50% oil (by wt) in biomass.

Theoretically, algae do promise many advantages but several obstacles will still need to be overcome in practical. Technological barrier and low cost effectiveness are some of the limitations to commercial algae oil biodiesel production. Specifically for Malaysia, scarcity of ecological information on Malaysian algae strains has to be overcome by encouraging more scientific assessment and phenological studies on important indigenous algae strains. As other countries have been promoting the usage of algae for biodiesel production, Malaysia should not be left behind as well. The distinct advantages brought by algae in biodiesel production are believed to be able to complement with other biodiesel feedstocks primarily palm oil.

7. Recommendations

Malaysia is a net exporter country of petroleum. However, with the current production rate and domestic consumption growing at around 6% per annum, the status will be changed by 2015 [66]. Therefore, emphasis on higher utilization of renewable energy such as biodiesel is of utmost importance. Until now, Malaysia's effort in promoting biodiesel is commendable and has earned praises from many quarters. However, in order to maintain its status as one of the leading producers of biodiesel in the world, there are still several key areas in which it will need to improvise.

As outlined previously by Malaysian government in the National Biofuel Policy, the planned strategies include establishment of an industry standard for biodiesel quality by Standard and Industrial Research Institute of Malaysia (SIRIM) and encouraging the use of biodiesel among public by providing biodiesel pumps at petrol stations. So far, none of them have been carried out effectively. Malaysian government should ensure that the B5 mandate of biodiesel blend be implemented as soon as possible covering private diesel-powered vehicles as well. Higher incentives should also be allocated for manufacturing plants which repowering their energy requirements using renewable energy such as biodiesel. Without strong support from local demand, Malaysia's biodiesel industry will be continuously subjected to numerous threats in the highly volatile exportation market. In view of this, it will be imperative for Malaysian government to work closely with other oil and gas companies to ensure that the required blending infrastructure, distribution network and logistical conditions are ready to support the B5 biodiesel blend implementation. Furthermore, an industry standard for biodiesel should also be enforced effectively in order to regulate the quality of biodiesel in the local market. The international standards such as ASTM D 6751 and EN 14214 can serve as guidelines but Malaysia should not be over-dependant on them as the biodiesel quality requirements for local usage are a little different such as in terms of pour point and cloud point. In 2008, Malaysian government had already approved the first Malaysia Biodiesel Standard (MS 2008:2008) with support from vehicle producers. However, few biodiesel companies have really utilized the standards comparing to ASTM D 6751 and EN 14214. Solid establishment of recognized standards will be one of the essential requirements for the engine manufacturers to extend their warranty covering the usage of biodiesel in their engines and thus giving more confidence for the public to switch to biodiesel.

Even though the implementation of B5 biodiesel blend should be carried out at the earliest time possible, Malaysian government has to ensure that the mandate will be flexible enough to prevent any adverse effects it could cause. Ever since the increment of the relative price of crude palm oil to crude petroleum oil as shown in Fig. 5, many people has perceived that the mandatory blending of biodiesel will increase the fuel cost as well as the retail price for consumers. As a result, the producers will need to either absorb the extra cost themselves or let the consumers paid for a more expensive fuel. In the long run, this will be detrimental to the country's economy and society. Therefore, maintaining certain degree of flexibility will enable the blending ratio to be lowered whenever the cost of feedstock becomes too expensive. Malaysian government should also urge its banking industry such as Bank Negara to aid biodiesel companies in terms of refinancing existing investments during high feedstock costs. On the other hand, subsidies given by Malaysian government on petroleum-derived diesel should be progressively relocated to biodiesel blends once the B5 mandate has been implemented. In the current scenario, Malaysia's biodiesel industry has to compete with one of the lowest petroleum-derived diesel prices in the region. Malaysian government has been setting the retail prices below the market price by compensating the retailers through subsidies. The annual road tax for diesel-powered vehicles is also significantly higher than petroleum-powered vehicles due to the consideration that their engines released more harmful emissions to the environment [87]. These have largely deterred the development of biodiesel industry for local market.

For now, most of the biodiesel research in Malaysia has been conducted by MPOB which focussed primarily on palm oil as the feedstock. Much of the research work is carried out with the best interest to the oil-palm plantation in mind. So far, Malaysia still lacks a centralized research centre which truly championing for the development of biodiesel regardless of feedstock. The concept of "Plantation University" is a novel idea being suggested to train the necessary human capital and undertaking further research and development activities in oil-palm industry [88]. This concept should be extended to other biodiesel plantations as well such as jatropha and algae to prepare Malaysia moving towards multi-feedstock biodiesel production in the future. Under this centralized research centre, higher coordinated efforts and cooperation among all quarters could be attained in order to develop a more comprehensive and widely accessible technology package for biodiesel. Moreover, a centralized centre for exchanging scientific information is also beneficial in terms of monetary and time savings as redundancy in similar research activities could be minimized. Besides assembling and verifying biodiesel data information, this one-stop centre also has a great potential to serve as the primary linkage between biodiesel researchers and industry developers.

In U.S., most of the issues pertaining to the biodiesel are referred to an industry trade association called National Biodiesel Board (NBB). It was set up in 1992 to introduce the usage of soybean-based biodiesel in U.S.'s fuel mix. Now, NBB has developed into the single coordinating body for U.S. biodiesel development where companies interested in venturing into U.S. biodiesel industry are required to become a member before undergoing a series of certifications for their biodiesel products. Elsewhere in European countries, a similar body called European Biodiesel Board was founded in 1997. This non-profit organization is aimed to group major EU biodiesel producers and represents them as a single body to institutions of EU and other international organizations. Both organizations, NBB and EBB, have played a pivotal role in pushing for better biodiesel industry development in their respective country. Currently in Malaysia, most of the biodiesel industrial developers are very much working alone rather than concentrated their efforts together. This has hampered many significant milestones being achieved and could throw the entire Malaysia's biodiesel industry into disarray. One of the fine examples due to lack of regulatory body could be seen from the total of 91 biodiesel licenses being issued by Malaysian government and yet not more than 20% of the total licenses being utilized correctly. The setting up of Malaysian Biodiesel Association recently should play similar roles as its counterparts in U.S. and EU. It should act proactively to develop a comprehensive accreditation scheme and promote

larger cooperation among its members. It could help to identify biodiesel license holders who failed to start operation within the stipulated time and inform the authorities to revoke their licenses. Besides, it could also analyze problems confronted by the biodiesel industry and suggest solutions at economic, political, institutions, technical and legal levels. By then, the three main bodies comprise of government, researchers and industry developers will be able to form a closer framework in order to ensure a more sustainable development to transform Malaysia into a biodiesel producer hub in the region.

8. Conclusions

The previous R&D efforts by MPOB have laid a solid foundation for the development of biodiesel industry in Malaysia. The next course of action in the next few years will determine whether Malaysia will eventually progress to a leading biodiesel producer in the world or remain as a biodiesel market follower. Many other countries such as China, India and Philippines have expressed strong interest in biodiesel and are now evaluating their own indigenous vegetable oils as biodiesel feedstock. Even biodiesel industry itself faces strong competition from non-ester renewable diesel fuels, second generation biofuels and bioethanol. Malaysia's effectiveness in tackling the current biodiesel issues and versatility in responding to future biodiesel obstacles will decide its success in moving ahead of the chasing pack. Based on the review presented above, Malaysia should be able to gain the status as the leading biodiesel producer in the world by 2050 with suitable management skills and strategies. Recently, more and more potential biodiesel feedstock has been explored such as corn oil in distillers dried grains with soluble (DDGS), halophyte and soapstock. While palm oil biodiesel should remain to be the main focus in the near future, multi-feedstock biodiesel will be the long-term objective as more emphasis will be placed on the quality of products rather than feedstock alone. Extensive efforts to acquire leading technology knowledge for production of biodiesel in genetic engineering, proses intensification and energy integration will be required. More importantly, Malaysia should not neglect the development of relevant human capital as well so that Malaysia's biodiesel industry can ride on the success of both first class infrastructure and mentality together.

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